FIELD DEMONSTRATION OF ENHANCED SORBENT INJECTION FOR MERCURY CONTROL

QUARTERLY TECHNICAL PROGRESS REPORT

Reporting Period: April 1 – June 30, 2006

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Disclaimer

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AC	activated carbon
BOP	balance of plant
CMM	continuous mercury measurement
DOE	U.S. Department of Energy
EERC	Energy and Environmental Research Center
ESP	electrostatic precipitator
NETL	National Energy Technology Laboratory
NDIC	North Dakota Industrial Commission
PRB	Powder River Basin
SCA	specific collection area

Executive Summary

ALSTOM Power Inc., Power Plant Laboratories (ALSTOM) is currently carrying out a consortium-based, DOE-NETL program to demonstrate Mer-Cure™ technology, ALSTOM's novel and oxidation-based mercury control technology in coal-fired boilers. In the program, ALSTOM teams up with the University of North Dakota – Energy and Environmental Research Center (EERC), PacifiCorp, Basin Electric Power Cooperative (Basin Electric), Reliant Energy, North Dakota Industrial Commission (NDIC), and Minnkota Power.

The full-scale demonstration program consists of three seven-week long test campaigns in three independent host sites firing a wide range of coal ranks. These host sites include PacifiCorp's 240-MW_e Dave Johnston Unit 3 burning a Powder River Basin (PRB) coal, Basin Electric's 220-MW_e Leland Olds Unit 1 burning a North Dakota lignite, and Reliant Energy's 170-MW_e Portland Unit 1 burning an Eastern bituminous coal. These boilers are all equipped with an electrostatic precipitator (ESP).

In Mer-Cure™ technology, a small amount of sorbent (Mer-Clean™) is injected into a flue gas stream environment where the gaseous elemental mercury oxidation and removal is favorable. The sorbents are prepared with chemical additives that promote oxidation and capture of elemental mercury. The Mer-Cure™ mercury control technology offers a great opportunity for utility companies to control mercury in the most cost-effective manner while minimizing any balance-of-plant impact.

ALSTOM has made significant accomplishments in demonstrating the performance of Mer-Cure™ mercury control technology during the performance period. Highlights of the accomplishments are:

- Completed the Portland Station field test campaign;
- Removed the hardware system from Portland Station; and
- Data and sample analyses from the Portland Station are underway.

The results from the baseline and parametric testing at Reliant Energy's Portland Station testing are presented in this quarterly report. Analysis clearly demonstrates that ALSTOM's Mer-Cure™ system can achieve 90% removal of uncontrolled gaseous mercury. This was achieved at the injection rate of 7.7 lb/MMacf. This is a higher injection rate than was necessary at the previous two sites, which is believed to be due to SO_3 in the flue gas. SO_3 molecules compete with Hg over active sites on sorbent particles, inhibiting Hg capture. Measurement of SO_3 was carried out during long-term test period to understand the impact of SO_3 on the Mer-Cure™ system performance. Details will be discussed in the next reporting period.

In the next performance period, ALSTOM will complete Reliant Energy data and sample analysis. Laboratory-scale testing will also be carried out in a test setup while burning PacifiCorp and Basin Electric fuels.

INTRODUCTION

The overall objective of the DOE/NETL-sponsored project is to perform full-scale demonstration of Mer-Cure^{TM} technology in three coal-fired boilers burning coals of various ranks. These host sites include PacifiCorp's 240-MW_e Dave Johnston Unit 3 (DJ3) burning a PRB coal, Basin Electric's 220-MW_e Leland Olds Unit 1 (LO1) burning a North Dakota lignite, and Reliant Energy's 170-MW_e Portland Unit 1 burning an Eastern bituminous coal. These boilers are each equipped with an ESP (Table 1).

In the program, ALSTOM has demonstrated that greater than 70% of gaseous mercury in the flue gas can be captured by injection of enhanced sorbent at a feed rate significantly lower than required by standard activated carbon. ALSTOM will also collect performance data that can be used to accelerate commercialization of our mercury control technology.

Mer-Cure^{TM} technology applied to coal-fired power generation has the potential to be a cost-effective mercury control technology for the entire range of coals (bituminous, sub-bituminous, and lignite) and, in particular, the more challenging coals (for example, PRB and lignite coal). This control technology has low-capital costs (less than \$5/kW_e). It also requires a very small amount of additives for treatment, which results in low operating costs (0.5-0.75 mills/kWh) and minimal balance-of-plant (BOP) impact. As the technology is based on oxidation and adsorption of mercury, it is also applicable to all air pollution control configurations including wet scrubber and spray dryer-ESP/baghouse units. The main focus of the project, however, is coal-fired boilers with a cold-side ESP as the particulate control device, which represents 70% of the installed base in the United States.

The test program includes installation of equipment for the mercury control system, its operation under various firing conditions and measurement of elemental and oxidized mercury concentrations in the flue gas. The testing includes a one-week baseline mercury measurement and two weeks of parametric testing, followed by a four-week long-term testing. During the two-week parametric testing, the ALSTOM mercury control system has been operated with sorbents of several formulations at different sorbent injection rates to determine mercury oxidation and removal efficiencies. The optimum sorbent formulations and injection rates have been selected for the four-week testing to evaluate its long-term performance.

The EERC participates in the program by providing mercury measurement expertise. Continuous mercury measurement (CMM) has been carried out throughout the test period by installing CMM monitors before the injection location and after the ESP to provide both elemental and oxidized mercury concentrations in the stack gas. Ontario Hydro method will also be employed for some of the key test conditions to verify CMM data, to obtain mercury concentration and speciation measurements at ESP, and to ensure QA and QC of the measurements.

Table 1. Host site, coal and emission data for the field demonstration program

	PacifiCorp	Basin Electric	Reliant Energy
Unit	Dave Johnston 3	Leland Olds 1	Portland 1
Capacity (MW_e Gross)	240	220	172
Operation	Base-loaded	Base-loaded	Cycling
NO_x and SO_2 control	No low-NO_x Low sulfur coal	No low NO_x Low sulfur coal	Low-NO_x - LNCFS No sulfur control
Air Heater	Two Ljungstrom	Ljungstrom + Tubular	Ljungstrom
Particulate control (SCA in ft^2/kacfm)	CS-ESP (629)	CS-ESP (320)	CS-ESP (284)
Ash utilization	Sold for mine reclamation	Disposal	Disposal
Coal	Wyodak (PRB)	ND lignite	Bailey mine and Federal #2 coals
Higher Heating Value As-received (Btu/lb)	8,060	Lignite 6617	12,800 – 13,100
S in coal (%)	0.94	0.63	2-2.5%
Ash %	10.09	9.86	6-8%
Cl in coal (ppmwd)	<50		~1,500
Hg in coal (ppmwd)-dry	0.071	0.057-0.099	0.1-0.16
As-fired Hg level from Coal ($\mu g/Nm^3$)	7-9	6-10	10-16
Inlet Hg ($\mu g/m^3$)	10 – 12	8 – 9	11 – 13
Uncontrolled Hg Emission Stack ($\mu g/m^3$)	9 – 11	7 – 8	11 – 13
Removal Efficiency	0 – 20%	10%	0%
Carbon-in-ash	0.6 – 1.4%	< 0.2%	10-12%
Flue gas temp (ESP Inlet)	330-360^{o}F	375^{o}F	277^{o}F – full load

EXPERIMENTAL

Following are the major tasks being performed to achieve the project goals:

Task 1A. Design, Engineering and Fabrication of the Mer-Cure™ System for PacifiCorp's Dave Johnston Unit 3
Task 2A. Field Demonstration at PacifiCorp's Dave Johnston Unit 3

Task 1B. Design, Engineering and Fabrication of the Mer-Cure™ System for Basin Electric's Leland Olds Unit 1
Task 2B. Field Demonstration at Basin Electric's Leland Olds Unit 1

Task 1C. Design, Engineering and Fabrication of the Mer-Cure™ System for Reliant Energy's Portland Unit 1
Task 2C. Field Demonstration at Reliant Energy's Portland Unit 1

Task 3. Technology Transfer
Task 4. Program Management and Reporting.

During the current reporting period, Reliant Energy testing has been completed and analysis of data from Portland Station (Task 2C) has been started. Details of the project activities are described in this section.

Task 1A. Design, Engineering and Fabrication of the Mer-Cure™ System for PacifiCorp's Dave Johnston Unit 3

Task completed.

Task 2A. Field Demonstration at PacifiCorp's Dave Johnston Unit 3

Task completed.

Task 1B. Design, Engineering and Fabrication of Mer-Cure™ System for Basin Electric's Leland Olds Unit 1

Task completed.

Task 2B. Field Demonstration for Basin Electric Campaign

Task completed.

Task 1C. Design, Engineering and Fabrication of Mer-Cure™ System for Reliant Energy's Portland Unit 1

This task has been completed.

Task 2C. Field Demonstration for Reliant Energy's Portland Unit 1 Campaign

The field demonstration has been conducted in the current reporting period. Outages during the test campaign delayed the original test program by 4 weeks. Long-term testing has been completed in two boiler operating modes (ozone and non-ozone). At the conclusion of the testing, the Mer-Cure™ System was dismantled and removed from the test site.

Task 3. Technology Transfer

No activities for the task.

Task 4. Project Management and Reporting

Site reports are being prepared for the first two test campaigns. The revised date for delivery of the PacifiCorp's Dave Johnston Unit 3 and Basin Electric's Leland Olds Station 1 is November 30, 2006.

In the following reporting periods, further data and sample analysis will be conducted for the Portland test campaign. Laboratory-scale testing will also be performed at ALSTOM while firing coals from the test sites and injecting various Mer-Clean™ sorbents. These results will be reported in the upcoming quarterly reports.

RESULTS AND DISCUSSION

A full-scale demonstration has been completed at the Portland Station 1. The samples collected during field demonstration are being analyzed and the field data are currently being reduced. The results from the baseline and parametric testing are presented in this section. The long-term testing results will be presented in the next quarterly reports.

Table 2 lists the tasks carried out to complete the Portland Station 1 test campaign along with associated timeline. As listed, the baseline measurement of mercury level was conducted first for five days; the parametric testing immediately followed for 10 days; finally, the long-term testing was conducted by continuously operating the Mer-Cure™ system over a 30-day period.

At the Portland Station, ozone season starts on May 1st and ends on September 30th. During ozone season, the boiler is operated with deeper air staging in order to more aggressively control NOx emissions. This change in boiler operating condition affects mercury emission level. In order to investigate its effect, the long-term testing period was broken down into two periods, as listed in Table 2, covering both non-ozone season and ozone season.

Table 2. Reliant Energy Test Campaign Timeline

Tasks	Timeline
Baseline measurement	March 20 – March 24, 2006
Parametric Testing	March 25 – April 3, 2006
Long-term testing (non-ozone)	April 13 – April 28, 2006
Scheduled outage	May 12 – May 24, 2006
Long-term testing (ozone)	May 25 – June 12, 2006
System removal	June 13 – June 17, 2006

Figure 1 shows a schematic layout of the Portland Station showing various testing locations. The boiler has two Ljungstrom™ air heaters connected to an ESP. All of the flue gas coming out of the boiler was treated by Mer-Cure™ system with its sorbent injection at the economizer outlet. Gaseous mercury levels have been measured by the UND-EERC at the air heater inlet and ESP outlet using PS Analytical mercury monitors. An inertial separation probe was used at the air heater inlet to sample solids-free flue gas. Ontario Hydro measurements were made frequently during baseline, parametric and long-term testing to verify the CMM readings. Also, the SO_3 concentration in the flue gas was measured at three locations during test campaign using the controlled condensation method.

During test period, coal samples were collected from mills and composite samples were prepared; ash samples were collected from the ESP hoppers on a regular basis. Gas analysis data such as NOx, SOx, boiler exit O_2 and flue gas temperatures have been obtained from the plant data collection system. Also, the UND-EERC crew conducted independent measurements of flue gas composition as part of the Ontario Hydro mercury measurement efforts. Figure 1 also shows the average temperatures at various locations and load conditions. The measured flue gas temperatures at the air heater inlet and the ESP outlet for a full load condition were 640°F and 270°F, respectively. At a half load, the ESP outlet temperature decreased to 240°F. The measured O_2 concentrations at the air heater inlet and the ESP outlet were 3.5% and 7.6% O_2, respectively. ESP operating parameters have also been monitored in order to evaluate the impact of sorbent injection on ESP operation.

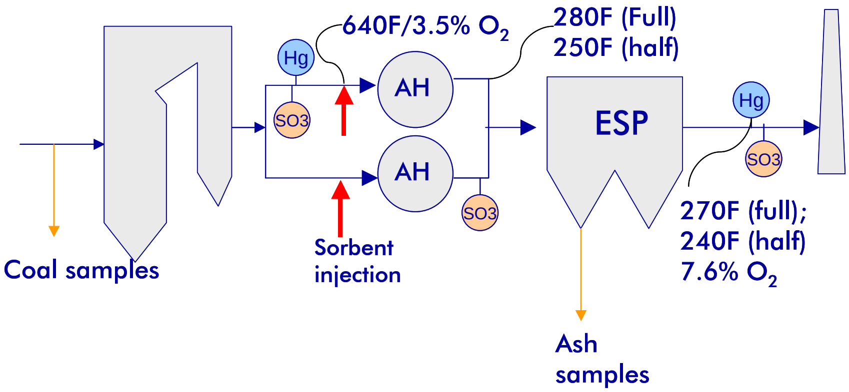

Figure 1. Schematic diagram of the plant layout and the sampling locations

Table 3 lists the average coal properties determined by analysis of coal composite samples. A total of 30 composite coal samples were collected and prepared from the four mills of Portland Station Unit 1 during the test campaign. The average mercury content of the coal and its standard deviation have been determined to be 0.11 µg/g dry coal, and 0.03 µg/g dry coal, respectively. The average chlorine content of the coal was 1,159 (±61) ppm on a dry basis.

Table 3. Reliant Energy Fuel Properties (Average)

Proximate analysis	As received	Dry basis
Total moisture (%)	6.22	N/A
Volatile matter (%)	31.85	33.97
Fixed Carbon (%)	54.44	58.05
Ash (%)	7.48	7.98
HHV (BTU/lb)	13,002	13,864
Ultimate analysis	As received	Dry basis
Moisture	6.22	N/A
C	70.79	75.49
H	4.89	5.21
O	7.23	7.43
N	1.41	1.51
S	1.98	2.11
Cl	1,144 ± 58 ppm	1,159 ± 61 ppm
Ash	7.48	7.98
Total	100.00	100.00
Hg (µg/g dry coal)	N/A	0.11 ± 0.03
Hg (lb/TBTU)	8.23 ± 2.13	8.23 ± 2.13

Figure 2 shows the variation of sulfur and mercury contents from composite daily coal samples obtained over 30 consecutive days. Analysis results show that the mercury content in the fuel varied widely from sample to sample (8.23 ± 2.13 lb/TBtu) much more than the sulfur content (3.04 ± 0.22 lb/MMBtu). The coefficients of variation for mercury and sulfur content were 25.9% and 7.2%, respectively. This variation comes from the fact that Portland Station fuels are shipped from two different mines – Federal #2 and Bailey. The variation of coal mercury content is especially significant between coal samples before (Federal # 2 with 10 lb/TBtu) and after 3/24 (Bailey with 3.7 lb/TBtu).

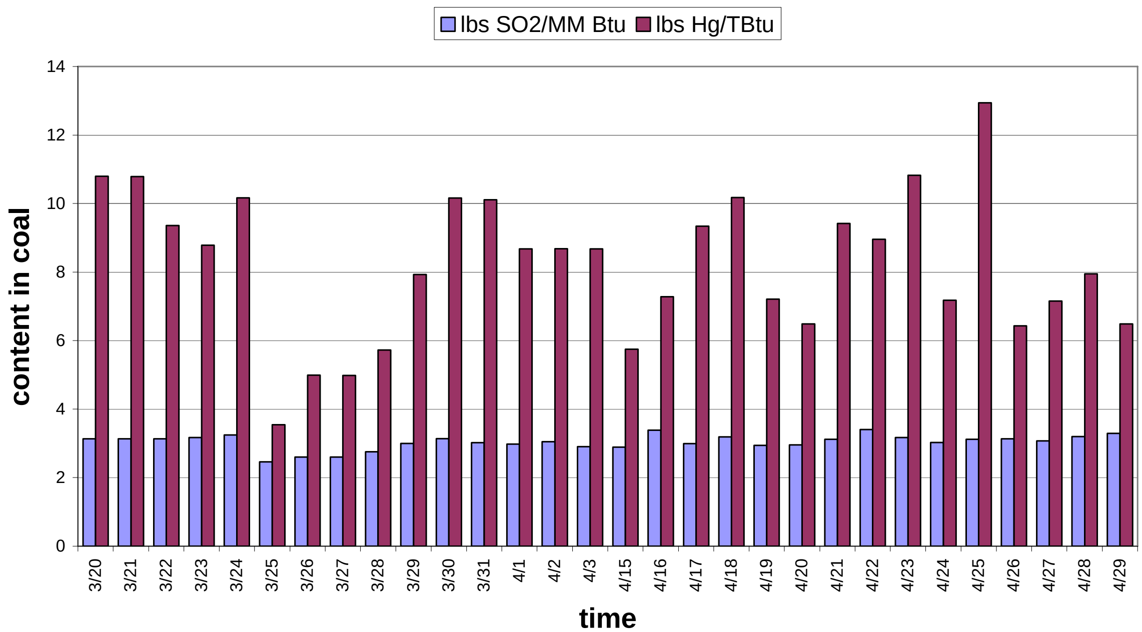

Figure 2. Variation of mercury and sulfur contents in coal from analysis of daily composite samples of Portland Station Unit 1 collected over 30 consecutive days

Figure 3 shows the gaseous total mercury levels measured by CMMs at the air heater inlet and the ESP outlet measured during the baseline and parametric test periods. Also presented are the gaseous mercury levels calculated from the mercury content of the coal (green horizontal bars) and the Ontario Hydro measurements at the air heater inlet (open squares) and ESP outlet (open circles) during the period.

Comparison of the coal data with the Ontario Hydro data shows that there is no native capture between the boiler and the air heater inlet. The CMM measurement at the air heater inlet is 25% lower than the Ontario Hydro measurement. The CMM measurement at the ESP outlet, however, agrees with the Ontario Hydro measurement. During the period, the baseline gaseous mercury levels varied widely also ranging from 3 $\mu g/m^3$ to 16 $\mu g/m^3$.

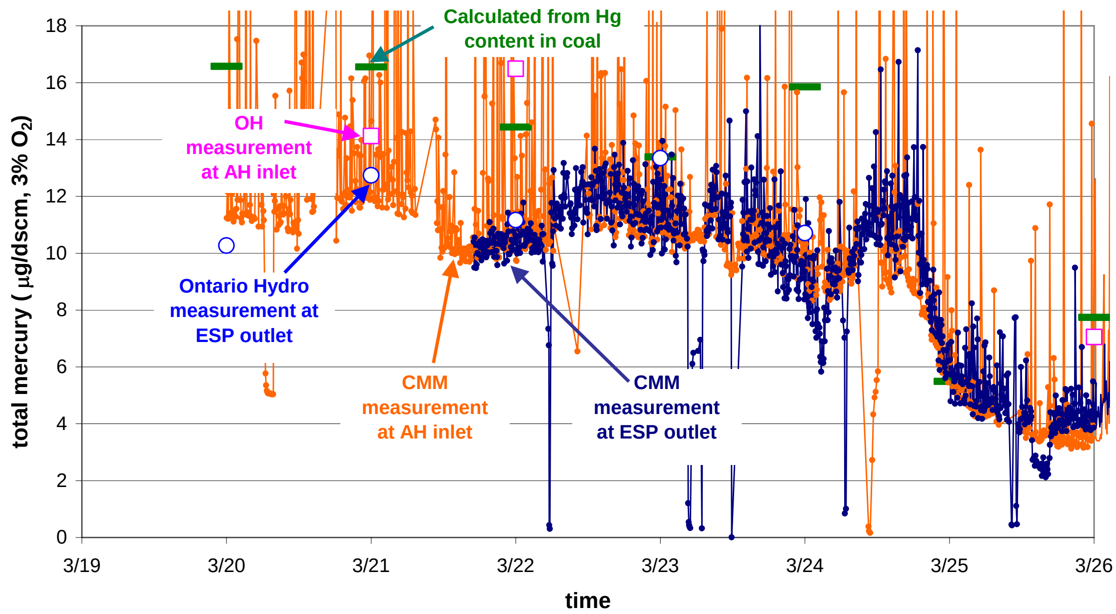

Figure 3. Gaseous mercury measurements at the ESP outlet (navy blue) and the air heater inlet (orange). Mercury content in the fuel is also shown in green bars and Ontario Hydro measurement results are shown in open circles and squares.

The wide fluctuation observed during baseline measurement suggested that an average mercury level calculated over the baseline measurement period is not an appropriate basis for calculation of mercury removal efficiency during parametric testing of the Mer-Cure™ technology. As shown in Figure 3, however, the agreement between the air heater inlet and ESP outlet CMM measurements indicates that, for the purpose of evaluating the mercury removal performance, the air heater inlet CMM measurement could be used as a substitute for the uncontrolled baseline mercury emission level at the ESP outlet.

Figure 4 shows a snapshot of changes in gaseous mercury levels at the air heater inlet and the ESP outlet during parametric testing at Portland Station. The ESP outlet measurements show that approximately one third of the total gaseous mercury was in elemental form throughout the parametric testing period. Before injection (between 0:00 and 08:00 on 3/26), the CMM readings for total mercury at the air heater inlet and the ESP outlet were approximately the same. At around 9:30, the Mer-Cure™ system was turned on and the Mer-Clean™ sorbent 8 was injected at 6.6 lb/MMacf (test condition 1). After 4 hrs of continuous injection, the total mercury level at the ESP outlet leveled off at 1 $\mu g/m^3$, giving 75% reduction. The injection rate was then reduced to 2.8 lb/MMacf (test condition 2) at 19:30, and the ESP outlet reading increased to 1.6 $\mu g/m^3$ giving 55% reduction. The parametric testing was continued in this fashion with various sorbents (Mer-Clean™ sorbents 2, 4, 6, and variations of 8) at a range of sorbent feed rates.

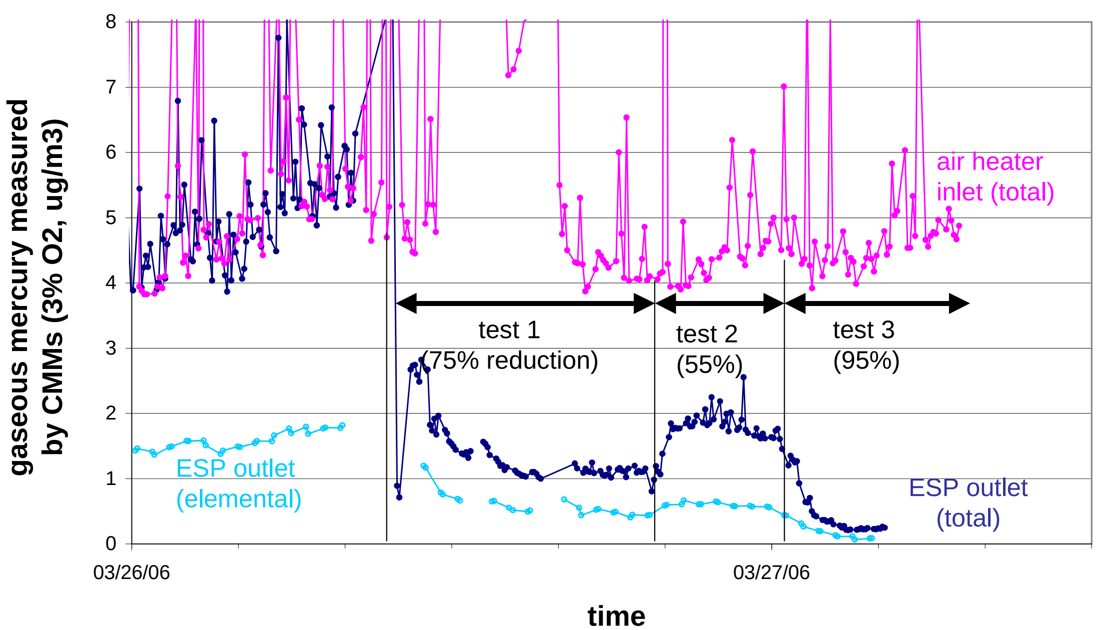

Figure 4. CMM measurements at the air heater inlet and ESP outlet during parametric testing. Testing was carried out during non-ozone season. At the ESP outlet, the approximately one third of the total mercury is in elemental form.

The performance results are summarized in Figure 5. In the figure, mercury removal efficiency is shown as a function of the sorbent feed rate (in lb/MMacf, or pounds per million actual cubic feet, where the "actual" condition refers to the actual ESP outlet condition, i.e., 270°F and 7.6% O_2). The reported removal efficiency was calculated with the air heater inlet CMM concentration of gaseous mercury as the basis for uncontrolled emissions. The graph was constructed based on the data collected while the boiler was operated at a full load.

Among the Mer-Clean™ sorbents tested, Mer-Clean™ 8-21 demonstrated the best performance, exhibiting 90% reduction at 7.7 lb/MMacf. This is a higher injection rate than was necessary at the previous two sites, which is believed to be due to SO_3 in the flue gas. SO_3 molecules compete with Hg over active sites on sorbent particles, inhibiting Hg capture. Measurement of SO_3 was carried out during long-term test period to understand the impact of SO_3 on the Mer-Cure™ system performance.

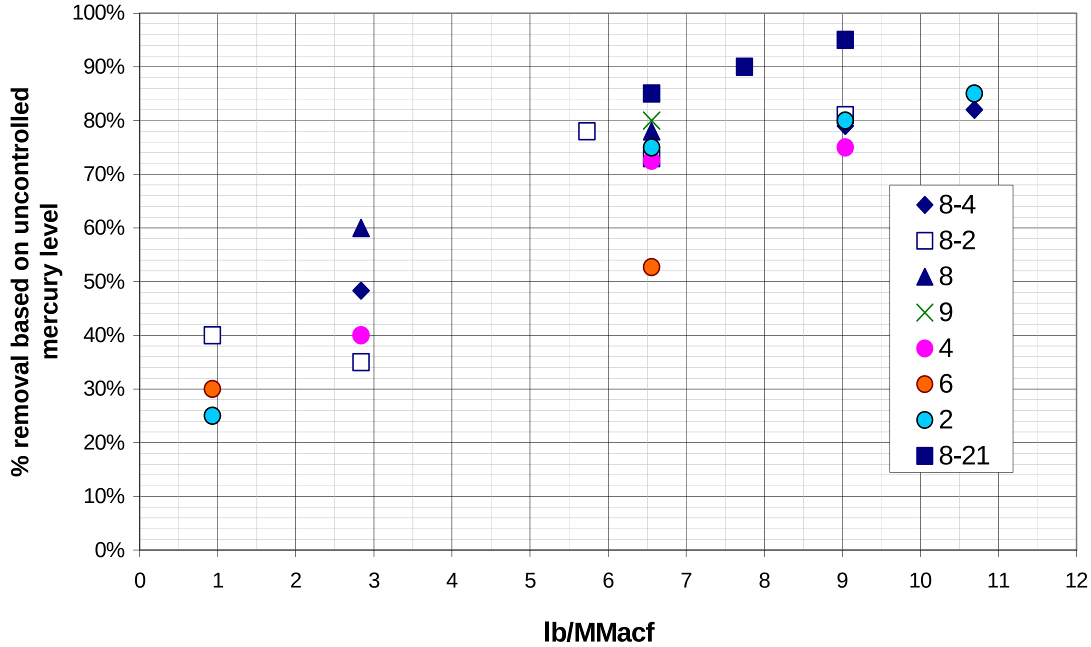

Figure 5. Performance of Mer-Cure™ system with various Mer-Clean™ sorbents. Testing conducted while the boiler was operated at a full load.

SUMMARY

Field demonstration of the Mer-Cure™ system has been completed at Reliant Energy's Portland Unit 1. Some of the preliminary test results are presented in this report. Following is the summary of Portland test campaign results discussed in this quarterly report:

- The mercury content of the fuels fired at Portland Station 1 varied widely on a daily basis with its average of 8.23±2.13 lb Hg/TBtu. The sulfur content, on the other hand, did not vary as much, with its average of 3.04 ± 0.22 lb SO_2/MMBtu. This variation was due to the station alternating the fuels from two different coal mines.

- The baseline gaseous mercury levels, as a result, varied widely also ranging from 3 $\mu g/m^3$ to 16 $\mu g/m^3$.

- According to the CMM measurements at the ESP outlet, the elemental mercury was approximately one third of the total mercury before injection of the sorbent. The mercury speciation did not change significantly during injection.

- Parametric testing performed during non-ozone season shows that at Portland Station 1, the uncontrolled mercury emissions can be reduced by 90% by injecting Mer-Clean™ 8-21 sorbent at 7.7 lb/MMacf.

- The injection rate required for 90% removal is higher than that required for the previous two sites firing lower rank coals. This is believed to be due to the presence of relatively high concentration of SO_3 in the flue gas. Measurement of SO_3 has been carried out in the long-term testing period and will be presented in the next quarterly report.

MILESTONES AND SCHEDULE

All of the three field test campaigns have been completed. PacifiCorp and Basin Electric test results have been reported in the previous quarterly reports. Part of the Reliant Energy test results is presented in this quarterly report. Analysis of the data and solids samples from Reliant Energy's Portland Station will be completed during the next quarter and reported subsequently. Laboratory-scale testing of the Mer-Cure™ system will also be conducted during the next quarters. Site reports for the first two test sites are scheduled for delivery by November 30th, 2006.

Table 4. Schedule for Mer-Cure™ demonstration

ID	Task Name
1	**Design, Engineering, and Fabrication, Dave Johnston Unit**
2	Design and Engineering of System Architecture
3	Component Fabrication and Testing
4	Assembly and Shipping
5	**Field Demonstration, Dave Johnston Unit 1**
6	Project Kickoff Meeting, Environmental/Regulatory Approvals
7	Installation, Checkout, and Commissioning
8	System Setup - Milestone 1
9	Testing
10	Removal
11	Data Analysis and Site Report
12	Site Report - Milestone 2
13	**Design, Engineering, and Fabrication, Leland Olds Unit 1**
14	Design and Engineering of System Architecture
15	Component Fabrication and Testing
16	Assembly and Shipping
17	**Field Demonstration, Leland Olds Unit 1**
18	Project Kickoff Meeting, Environmental/Regulatory Approvals
19	Installation, Checkout, and Commissioning
20	System Setup - Milestone 3
21	Testing
22	Removal
23	Data Analysis and Site Report
24	Site Report - Milestone 4
25	**Design, Engineering, and Fabrication, Portland Unit 1**
26	Design and Engineering of System Architecture
27	Component Fabrication and Testing
28	Assembly and Shipping
29	**Field Demonstration, Portland Unit 1**
30	Project Kickoff Meeting, Environmental/Regulatory Approvals
31	Installation, Checkout, and Commissioning
32	System Setup - Milestone 5
33	Testing
34	Removal
35	Data Analysis and Site Report
36	Site Report - Milestone 6
37	**Technology Transfer**
38	Technology transfer
39	**Program Management and Reporting**
40	**Program Management**
432	**Reporting - As Needed**
463	Final Report
464	Final Report - Milestone 7

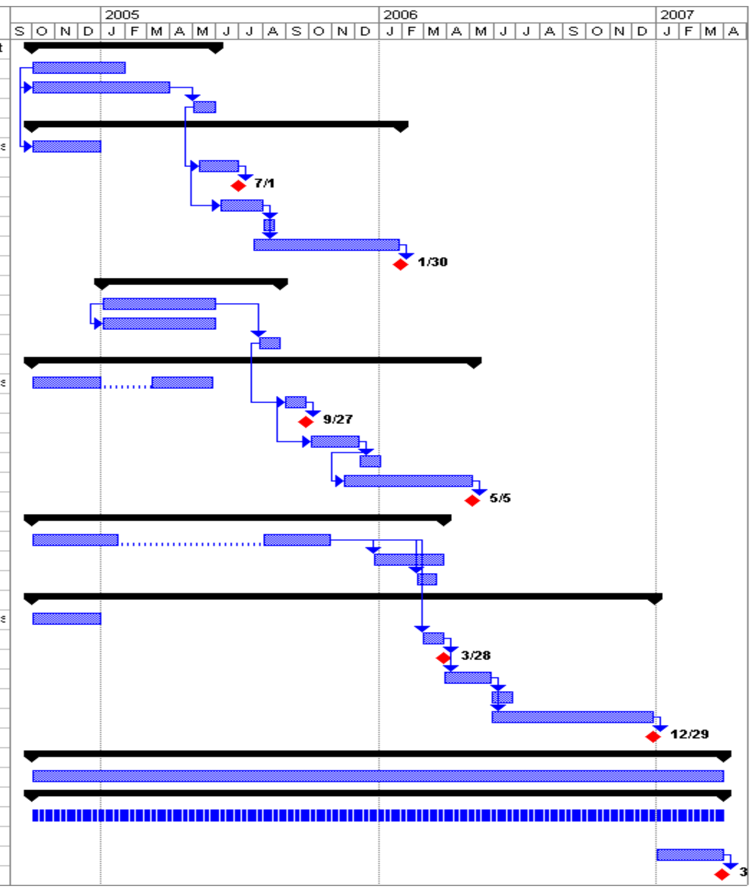

Table 5. Milestones and Deliverables

Milestone/ Deliverable	**Original**	**Revised**	**Actual**
1. System setup – Dave Johnston (PacifiCorp)	7/1/05		6/18/05
2. Site Report – Dave Johnston (PacifiCorp)	1/30/06	11/30/06	
3. System setup – Leland Olds (Basin Electric)	9/27/05		9/29/05
4. Site Report – Leland Olds (Basin Electric)	5/5/06	11/30/06	
5. System setup – Portland (Reliant)	3/28/06	3/24/06	
6. Site Report – Portland (Reliant)	12/29/06		
7. Final Report	3/30/07		